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ORIGINAL ARTICLE

Performance of particleboard manufactured using air-injection press I: effects of air-injection press on preventing blowout of board manufactured from low-moisture particles

Hiroshi Saotome · Hideaki Korai · Takahiko Iida · Tomoko Hamano · Kensuke Kawarada · Masaharu Ohmi

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Abstract An air-injection press (AIP) was developed to prevent accidental blowouts of boards during production. In this study, the effects of the AIP on preventing blowouts were investigated by artificially creating a blowout-prone condition, and the press was shown to be effective in preventing blowouts. The modulus of rupture of the boards was almost constant irrespective of pressing time. Longer pressing time resulted in higher internal bond strength when pressed at 170 °C. The thickness swelling of the boards pressed at 170 or 190 °C was almost uniform irrespective of pressing time, and the manufactured boards showed performance similar to those manufactured with an ordinary press. The AIP prevented blowouts sufficiently even when the pressure of the injected air was reduced, and this reduction did not adversely decrease the performance of the boards. Air injection reduced formaldehyde emissions from the board.

Keywords Air-injection press · Particleboard · Blowout · Board performance · Formaldehyde emission

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H. Saotome · H. Korai (✉)
Forestry and Forest Products Research Institute,
Tsukuba 305-8687, Japan
e-mail: korai@ffpri.affrc.go.jp

T. Iida · T. Hamano · K. Kawarada
Tokyo Metropolitan Industrial Technology Research Institute,
Tokyo 135-0064, Japan

M. Ohmi
Faculty of Agriculture, Tokyo University of Agriculture
and Technology, Tokyo 183-8509, Japan

Introduction

When manufacturing particleboard, vapor can become trapped between the wood particles during the hot pressing process and cause a blowout on the board when the press is opened. This damage, which is caused by vapor generated during pressing, can be prevented by drying the particles and lowering the moisture content in advance. However, blowout may still occur accidentally in large boards that are manufactured in a factory production line even when particles of low moisture content are used. Since this damage occurs at the last stage of the manufacturing process, all preceding procedures are wasted, causing a sharp drop in productivity, so it is important to prevent accidental blowouts to increase productivity. Few studies were reported about blowout of particleboards [1]. Although the mechanisms of blowouts of the board manufactured from low-moisture particles are not well understood, tests were conducted by focusing on inhibition of moisture movement during hot pressing, which is likely to be a major factor.

The air-injection press (AIP) was developed to manufacture particleboard from high-moisture particles of 25 % moisture content by discharging vapor from the board, to save energy during manufacture by eliminating the process of drying particles. The authors have reported the basic performance of boards manufactured using the AIP [2], the effects of the size of the air-injection holes [3], and the effects of pressing temperature [4]. The AIP is likely to be also effective for preventing accidental blowouts of boards manufactured from dry particles.

Blowout never occurs in small boards manufactured in the laboratory from low-moisture particles. In order to examine the effects of the AIP, a condition that induces blowouts needs to be created. Boards were manufactured with a metal frame placed so as to close the board edges

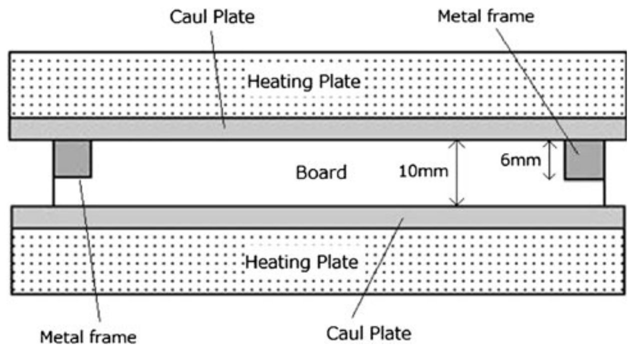

Fig. 1 Schematic view of the hot press with the metal frame

(Fig. 1). The frame inhibited vapor from escaping from the board, and the board blew out. In this study, the blowout prevention effect of the AIP was examined using the metal frame.

The AIP was also shown to discharge the binder together with vapor when boards were manufactured from high-moisture particles [2]. Similarly, the press also reduced formaldehyde emissions from the board [3]. The study [3] suggested that the AIP may also discharge the binder from boards manufactured from low-moisture particles, decreasing the board performance, and may also reduce formaldehyde emissions from the boards. In this study, boards were manufactured from low-moisture particles using the AIP to investigate the effects of air injection on board performance and formaldehyde emission. In particular, the reduction of formaldehyde emission is widely concerned on manufacture of wood composite boards [5–9].

Experimental method

Metal frame for artificially inducing blowouts

A metal frame (frame thickness and width: 6 mm, inner dimensions: 270 × 270 mm) was placed on a formed mat to artificially induce blowout (Fig. 2). The frame inhibits water vapor generated during pressing from escaping from the board and induces blowout (Fig. 1). An edge of the board manufactured using the metal frame is shown in Fig. 3. As in the previous studies [3, 4], the diameter of the air-injection holes was 1 mm; the spacing between the centers of adjacent holes was 25 mm; and there were 121 holes in an area of 250 × 250 mm. Air injection was started after the board was compressed to the final thickness and stopped 15 s before releasing the press.

Conditions of particleboard manufacture

The boards were manufactured from particles prepared from wood waste for core layers of the particleboard (Japan Novopan Industrial Co., Ltd.). The mean length (standard deviation) of 200 measured particles was 15.4 (6.69) mm. The binder used was a urea–formaldehyde resin (Oshika Co., Ltd.), which had a solid content of 65 % and viscosity of 0.14 Pa s. Curing agent of 10 % ammonium chloride solution was added to the binder to constitute 10 % (by weight).

Fig. 2 Mat of wood particles and the metal frame

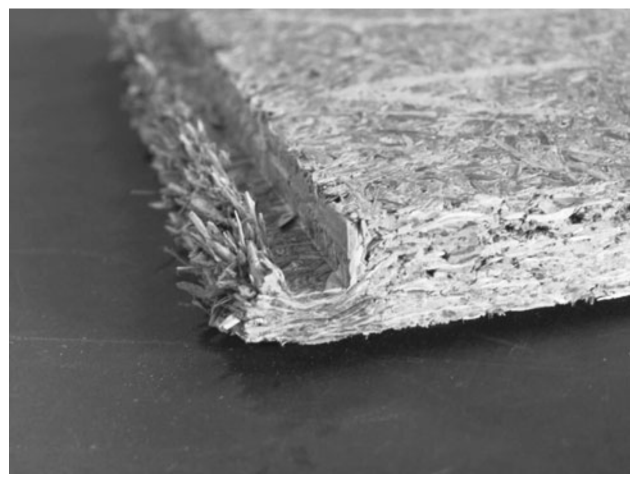

Fig. 3 Edge of the board hot-pressed while placing the metal frame

The binder was sprayed on the particles using a spray gun so as to constitute 10 % of the particles (by weight) while stirring the particles in a blender. The particles sprayed with binder were spread into a mat form by hand. The moisture content of the particles after the application of the binder was 14.5 %. The dimensions of the board were 300 × 300 × 10 mm, and the target density was 0.7 g/cm^3.

The conditions of board manufacture were shown in Table 1. Boards manufactured without using the AIP and

Table 1 Conditions of board manufacture

Pressing method	Frame Yes / No	Pressing temperature (°C)	Pressing time (min)	Air-injection pressure (MPa)	Figures and tables
Ordinary press (control)	No	170	4	0	Table 2
Ordinary press (control)	No	190	4	0	Table 2
Ordinary press	Yes	170	4, 6, 8	0	Blowout
Ordinary press	Yes	190	4, 6, 8	0	Blowout
Air-injection press	Yes	170	4, 6, 8	0.55	Figs. 4, 5, and 6
Air-injection press	Yes	190	4, 6, 8	0.55	Figs. 4, 5, and 6
Air-injection press	Yes	170	4	0.20, 0.40, 0.55	Figs. 7, 8, and 9
Air-injection press	Yes	190	4	0.20, 0.40, 0.55	Figs. 7, 8, and 9
Ordinary press	No	170, 190	4	0	Table 3
Air-injection press	Yes	170, 190	4	0.55	Table 3

the metal frame were used as controls. Two control boards were manufactured for each pressing temperature of 170 and 190 °C by pressing for 4 min.

First, to examine whether a board can be manufactured without blowout even without using the AIP, the metal frame was placed on a formed mat and was hot pressed without injecting air (Table 1). This corresponds to the ordinary method used for manufacturing boards. Pressing temperatures of 170 and 190 °C and pressing times of 4, 6, and 8 min were tested.

Next, to examine the effects of air injection, the metal frame was placed on a formed mat (Fig. 1) and was hot pressed by injecting air (Table 1). Pressing temperatures were 170 and 190 °C, and pressing times were 4, 6, and 8 min. The air injection pressure was 0.55 MPa.

To understand the effects of air-injection pressure, boards were manufactured by pressing at 170 and 190 °C for 4 min by injecting air at 0.20, 0.40 and 0.55 MPa (Table 1). In this study, one board was manufactured for each condition except for the controls. For formaldehyde emission measurement, boards were manufactured by pressing at 170 and 190 °C for 4 min (Table 1). The formaldehyde emissions from boards manufactured by injecting air at 0.55 MPa and not injecting air were compared.

Performance tests

The moisture content of the boards manufactured was adjusted before the tests by leaving the boards in a thermo-hygrostat at 20 °C and 65 % relative humidity until the weight stabilized. The modulus of rupture (MOR), internal bond strength (IB) and thickness swelling (TS) were determined according to JIS A 5908 [10]. The number of test specimens was 5, 8 and 7, respectively, and the number of control specimens was double: 10, 16 and 14, respectively. Formaldehyde emissions were measured according to JIS A 5908 [10].

Table 2 Performance of the control boards

Pressing temperature (°C)	MOR (MPa)	IB (MPa)	TS (%)
170	20.3 (2.21)[a]	0.70 (0.25)[b]	22.9 (1.30)[c]
190	19.8 (1.56)[a]	0.77 (0.06)[b]	27.3 (3.33)[c]

The numbers in parentheses indicate standard deviations

MOR modulus of rupture, *IB* internal bond strength, *TS* thickness swelling

[a] Not statistically significant

[b] Not statistically significant

[c] Statistically significant at 0.1 % level

Results and discussion

Board manufacturability

With the 6-mm thick metal frame placed, all boards blew out at both 170 and 190 °C for all pressing times when air was not injected (Table 1). On the other hand, with air injection, boards could be manufactured by pressing for 4 min at 170 or 190 °C. As reported in a previous study [2], boards needed to be pressed for 6 min when manufactured from high-moisture particles (high-moisture board). From low-moisture particles, boards could be manufactured with shorter pressing time (low-moisture board). The AIP prevented blowout of low-moisture boards, and so is likely to be effective in preventing accidental blowouts in factory production lines.

Performance of the control boards

The performance of the 170 and 190 °C control boards is shown in Table 2. MOR was 20 MPa in both types of board. The IB values of the 170 and 190 °C boards were 0.70 and 0.77 MPa, respectively, which were not significantly different statistically, and satisfied the JIS Type 18 particleboard requirements [10]. As urea–formaldehyde

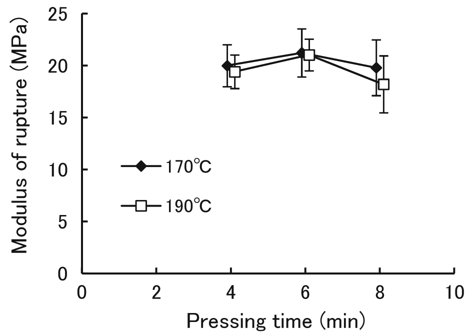

Fig. 4 Relationship between pressing time and modulus of rupture. *Vertical bars* indicate standard deviations

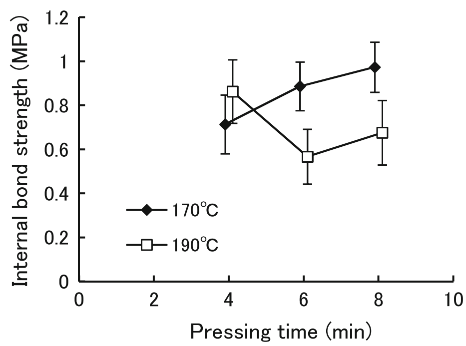

Fig. 5 Relationship between pressing time and internal bond strength. *Vertical bars* indicate standard deviations

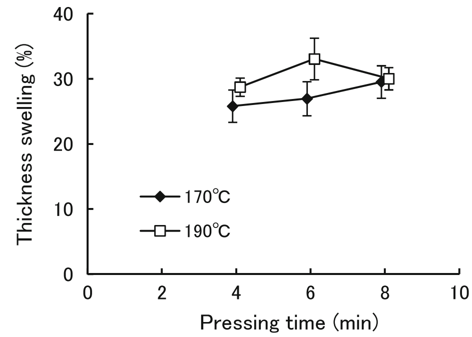

Fig. 6 Relationship between pressing time and thickness swelling. *Vertical bars* indicate standard deviations

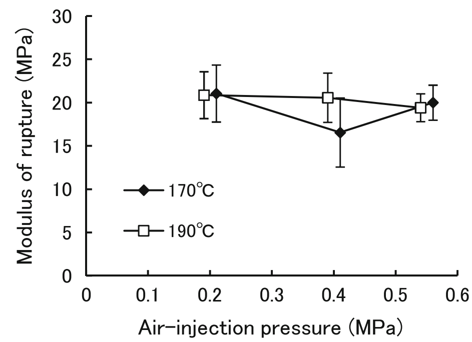

Fig. 7 Relationship between air-injection pressure and modulus of rupture. *Vertical bars* indicate standard deviations

resin was used as the binder without the wax emulsion, the TS of the 170 and 190 °C boards was 22.9 and 27.3 %, respectively, which were very high. High TS of boards bonded by urea–formaldehyde resin was reported in many papers [11–14]. High TS of this study was the same results as the past papers reported.

Effects of pressing time on board performance

Figure 4 plots MOR against pressing time. In all boards, mean of the MOR was above 18 MPa. The value was almost constant irrespective of pressing time for both pressing temperatures of 170 and 190 °C. In a previous study [4], air injection reduced MOR, but in this study, the MOR of the boards manufactured with air injection almost corresponded to the controls indicated in Table 2, showing that the air injection did not reduce the MOR. The amount of the vapor from low-moisture particles was less than that of high-moisture particles, which presumably resulted in no hydrolysis of urea–formaldehyde resin caused by the vapor.

Figure 5 shows the relationship between IB and pressing time. For a pressing time of 4 min, IB of 190 °C boards was slightly higher than that of 170 °C boards (statistically significant at 5 % level), but IB was higher in the 170 °C boards than in the 190 °C boards when they were pressed for 6 or 8 min. When pressed at 170 °C, IB increased as the board was pressed for longer. Compared to the 170 °C control, air injection at the same temperature caused no statistically significant difference in 4 min, but higher IB in 6 and 8 min with 0.89 and 0.97 MPa, respectively. On the other hand, at 190 °C, 6 and 8 min of pressing reduced IB from that of the 4-min board to 0.57 and 0.68 MPa, respectively. The causes of low IB at 190 °C are unknown and need to be investigated. Compared to the 190 °C control, the 4-min board manufactured with air injection showed higher IB (statistically significant at the 5 % level). This was likely because vapor was discharged from the board, accelerating the hardening of the binder. In a previous study [4], air injection reduced the MOR and increased the IB of high-moisture boards. In this study, the low moisture-particles were used. It was first predicted that air injection would discharge the binder together with vapor and would lower the MOR and IB of boards, but in fact it increased the value in some boards compared to the controls.

Figure 6 plots TS against pressing time. The TS values were higher in the 190 °C boards than in the 170 °C boards except for the 8-min 190 °C board. Compared to the controls, air injection caused no statistically significant difference in TS at both temperatures. Thus, it can be concluded that air injection does not increase TS.

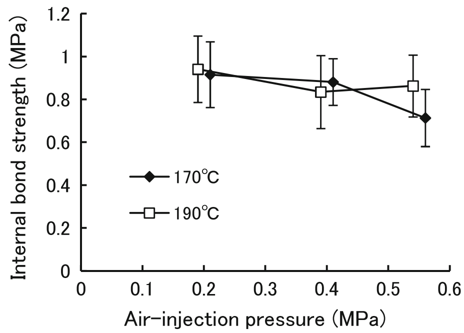

Fig. 8 Relationship between air-injection pressure and internal bond strength. *Vertical bars* indicate standard deviations

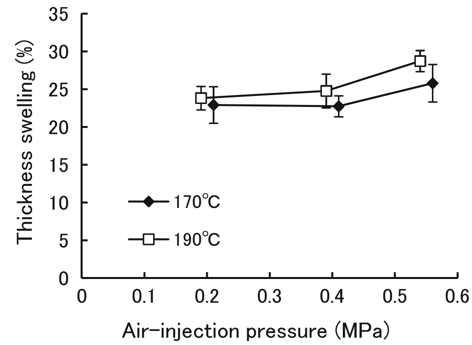

Fig. 9 Relationship between air-injection pressure and thickness swelling. *Vertical bars* indicate standard deviations

The tests showed that air injection prevented blowout of low-moisture boards and did not lower the MOR, IB and did not increase TS compared with those of the controls.

Effects of air-injection pressure on board performance

Figure 7 shows the relationship between the air-injection pressure and MOR. At 170 °C, the MOR was 16.5 MPa when air was injected at 0.40 MPa and was about 20 MPa for other air-injection pressures. In a previous study on high-moisture boards [3], MOR increased when the pressure of air injection was raised. However, the results for the low-moisture boards manufactured in this study were different.

Figure 8 plots IB against air-injection pressure. At 190 °C, IB was almost constant at 0.83–0.91 MPa irrespective of air-injection pressure. On the other hand, at 170 °C, IB was slightly low at 0.71 MPa when air was injected at 0.55. Compared to the controls, all air-injected boards showed similar or higher IB values. In the previous report [3], for high-moisture board, higher air pressure resulted in higher IB. This was likely because high-pressure air was needed to discharge the large amount of vapor generated from the high-moisture particles. On the other hand, for low-moisture board, there was no clear relationship between IB and air-injection pressure because they generated a small amount of vapor, which could be sufficiently discharged even by injecting air at low pressure. The same applied to MOR. The MOR and IB measurements showed that air injection even at low pressure could prevent blowout and manufactured boards of equivalent or better performance compared to the controls.

Figure 9 shows the relationship between TS and air-injection pressure. At both 170 and 190 °C, high TS values were observed at the air-injection pressure of 0.55 MPa. The TS was lower at 170 than at 190 °C when air was injected at 0.40 or 0.55 MPa. Higher air-injection pressure caused lower TS in high-moisture boards [3]. On the other hand, the TS values of low-moisture boards were smaller than the control values shown in Table 2, even when the air-injection pressure was low. An air-injection pressure of 0.20 MPa was found to be sufficient in order to gain low TS as well as high MOR and IB.

Table 3 Formaldehyde emissions

Pressing temperature (°C)	170		190	
	Air injection[a]	No air injection	Air injection[a]	No air injection
Formaldehyde emission (mg/L)	0.48	0.54	0.42	0.53

[a] Air-injection pressure of 0.55 MPa

Reduction of formaldehyde emissions by AIP

Table 3 shows the changes in formaldehyde emissions by air injection. Without air injection, the formaldehyde emissions from boards manufactured at 170 and 190 °C were 0.54 and 0.53 mg/L, respectively. With air injection, the emissions were 0.48 and 0.42 mg/L, showing that air injection reduced the formaldehyde emissions from the boards. This was likely because air injection discharged the formaldehyde, which was released in the board, together with vapor. According to a study by Tohmura et al. [15], formaldehyde emissions from hardened urea–formaldehyde resin were larger at higher temperatures (180 °C) than at lower temperature (150 °C). Therefore, air injection discharged a larger amount of formaldehyde during hot pressing at 190 °C than at 170 °C, resulting in less formaldehyde remaining in the board. In a previous study, air injection discharged formaldehyde from high-moisture boards and reduced the emissions [16]. A similar effect was also shown for low-moisture boards. Thus, air injection was shown to be effective also for reducing the formaldehyde emissions from boards as well as preventing blowouts.

Conclusions

Particleboards were manufactured using the AIP. The effects of the AIP were verified by artificially causing blowouts by placing a metal frame, and the following results were obtained:

1. Without the AIP, the use of the metal frame caused blowouts even when low-moisture particles were used and impeded board manufacture. On the other hand, with the AIP, boards could be manufactured with 4 min of hot pressing.
2. MOR was almost constant irrespective of pressing temperature and time. IB increased at 170 °C with increasing pressing time. TS was lower at 170 °C than at 190 °C in general. It was shown that the pressing temperature of 170 °C was appropriate in terms of board performance and energy efficiency.
3. MOR and IB were not reduced by the air-injection pressure and were almost constant. TS was low at air pressures of 0.20 and 0.40 MPa. Therefore, the air-injection pressure of 0.20 MPa was concluded to be effective for preventing blowouts without deteriorating the board performance.
4. Air injection reduced the formaldehyde emissions from boards manufactured from low-moisture particles.

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